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METHOD FOR PRODUCING Al-Mg-Si ALLOY SHEET EXCELLENT IN BAKE-HARDENABILITY AND HEMMABILITY

TECHNICAL FIELD

The present invention relates to a production method for obtaining an Al-Mg-Si alloy sheet that is abundant in hemmability while simultaneously having a high age-hardening ability, by casting a thin slab by continuous casting of an Al-Mg-Si alloy, performing a homogenization treatment, then cold rolling, and performing a solution treatment in a continuous annealing furnace as needed. According to the present method, it is possible to produce, at a low cost as compared to the conventional art, rolled sheets of Al-Mg-Si alloy that are suitable for forming by bending, press forming and the like of automotive parts, household appliances and the like.

BACKGROUND ART

Al-Mg-Si alloys have the property of increasing in strength when heat is applied during processes such as coating after forming, so that they are well-suited for use in automotive panels or the like. Furthermore, the production of sheets of the alloys by continuous casting and rolling has been proposed to reduce costs by improved productivity.

For example, Japanese Patent Application, First Publication No. S62-207851 discloses an aluminum alloy sheet for forming and method of production thereof, obtained by continuous casting of an aluminum alloy melt comprising 0.4-2.5% Si, 0.1-1.2% Mg and one or more among 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn and 0.3% or less of Zr, to form a 3-15 mm thick slab, cold rolling, then performing a solution treatment and quenching, characterized in that the maximum size of intermetallic compounds in the matrix is 5 μm or less.

Japanese Patent Application, First Publication No. H10-110232 discloses an Al-Mg-Si alloy sheet, obtained by preparing a direct cast rolled sheet of Al alloy comprising 0.2-3.0% Si and 0.2-3.0% Mg, containing one or more of 0.01-0.5% Mn, 0.01-0.5% Cr,

0.01-0.5% Zr and 0.001-0.5% Ti, and further containing 0-2.5% Cu, 0-0.2% Sn and 0-2.0% Zn, with Fe being limited to 1.0% or less and the remainder consisting of Al and unavoidable impurities, and further cold rolling, characterized in that the maximum crystal size in the metallic portion of the sheet is 100 μm or less and the maximum length of continuous Mg_2Si compounds on the surface layer portion is 50 μm or less.

Additionally, Japanese Patent Application, First Publication No. 2001-262264 proposes an Al-Mg-Si alloy sheet excelling in ductility and bendability, the aluminum alloy comprising 0.1-2.0% Si, 0.1-2.0% Mg, 0.1-1.5% Fe or one or more further elements chosen from among 2% or less of Cu, 0.3% or less of Cr, 1.0% or less of Mn, 0.3% or less of Zr, 0.3% or less of V, 0.03% or less of Ti, 1.5% or less of Zn and 0.2% or less of Ag, wherein the maximum size of intermetallic compounds is 5 μm or less, the maximum aspect ratio is 5 or less and the average crystal grain size is 30 μm or less.

Patent Document 1: Japanese Patent Application, First Publication No. S62-207851

Patent Document 2: Japanese Patent Application, First Publication No. H10-110232

Patent Document 3: Japanese Patent Application, First Publication No. 2001-262264

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

Alloy sheets that are used as outer panels in automotive body sheets or the like require exceptional hemmability and bake-hardenability. For this reason, Al-Mg-Si alloy sheets that excel in bendability and age-harden when heated have been sought. However, sheets produced by continuous casting and rolling have the drawbacks of poor hemmability and insufficient bake-hardenability after coating.

The problem to be solved by the present invention is to obtain, at a low cost, an Al-Mg-Si alloy sheet for forming that suppresses GP zones that are deposited during natural ageing when left at room temperature, achieves a high level of bake-hardening due to a reinforcement phase being quickly deposited upon heating during coating and baking, while simultaneously having abundant bendability.

Means for Solving the Problems

A thin slab of Al-Mg-Si alloy is continuously cast by a twin-belt casting machine, the cast thin slab is directly wound, subjected to a homogenization treatment under appropriate conditions, and cold rolled, then combined with a solution treatment in a continuous annealing furnace as needed, thereby fragmenting the compounds and raising the hemmability while simultaneously enabling the procedure to be considerably shortened. Furthermore, microsegregation is reduced by a homogenization treatment, and the cooling rate after the homogenization treatment is raised, thereby reducing the deposition of Mg_2Si while cooling, to obtain an aluminum sheet for automotive body sheets with excellent bake-hardenabiltiy and hemmability after a final anneal.

The present invention which solves the above problem relates to a method of producing aluminum alloy sheets characterized by winding into thin slabs, subjecting to a homogenization treatment, cold rolling, then subjecting to a solution treatment. Specifically, as recited in claim 1, it is a method of producing aluminum alloy sheets excelling in bake-hardenability and hemmability, comprising steps of casting, by means of a twin-belt casting method, an alloy melt comprising 0.30-1.00 wt% of Mg, 0.30-1.20 wt% of Si, 0.05-0.50 wt% of Fe, 0.05-0.50 wt% of Mn and 0.005-0.10 wt% of Ti, optionally further comprising at least one of 0.05-0.70 wt% of Cu or 0.05-0.40 wt% of Zr, the remainder consisting of Al and unavoidable impurities, to form a 5-15 mm thick slab at a cooling rate of 40-150 °C/s at a quarter-thickness of the slab; winding into a coil; subjecting to a homogenization treatment; cooling to 250 °C or less at a cooling rate of at least 500 °C/h; cold rolling; then subjecting to a solution treatment (invention according to claim 1).

In the above production method, the homogenization treatment preferably involves heating to 520-580 °C at a heating rate of at least 30 °C/h in a batch furnace, then holding at that temperature for 2-24 hours (invention according to claim 2).

The solution treatment preferably involves heating to 530-560 °C at a heating rate of at least 10 °C/s in a continuous annealing line, and holding for 30 seconds or less

(invention according to claim 3).

Furthermore, in the invention according to claim 3 mentioned above, the solution treatment may be followed by steps of cooling to room temperature at a cooling rate of at least 10 °C/s, then subjecting to a restoration treatment by holding for 30 seconds or less at 260-300 °C in a continuous annealing furnace, and cooling to room temperature at a cooling rate of at least 10 °C/s (invention according to claim 4).

Alternatively, in the invention according to claim 3 mentioned above, the solution treatment may be followed by steps of water-cooling to 250 °C or less at a cooling rate of at least 10 °C/s, then air-cooling to 60-100 °C at a cooling rate of 1-20 °C/s, coiling up, and subjecting to a preliminary ageing treatment by cooling to room temperature (invention according to claim 5).

Alternatively, in the invention according to claim 3 mentioned above, the solution treatment may be followed by steps of cooling to room temperature at a cooling rate of at least 10 °C/s, then subjecting to a restoration treatment by holding for 30 seconds or less at 260-300 °C in a continuous annealing furnace, cooling to 60-100 °C at a cooling rate of at least 1 °C/s, coiling up, and subjecting to a preliminary ageing treatment by cooling to room temperature (invention according to claim 6).

Effects of the Invention

According to the aluminum alloy sheet production method of the present invention, it is possible to obtain an aluminum alloy sheet with exceptional hemmability and bake-hardenability. Additionally, this production method is capable of obtaining an aluminum alloy sheet in an extremely short procedure and at low cost.

BEST MODE FOR CARRYING OUT THE INVENTION

The present invention relates to a method of producing a rolled sheet of Al-Mg-Si alloy, characterized by casting a thin slab by a twin-belt casting method, winding the slab directly onto a coil, subjecting to a homogenization treatment, then cold rolling, and further

subjecting to a solution treatment.

In the present invention, an alloy melt consisting of the aforementioned composition is cast into a slab 5-15 mm thick at a cooling rate of 40-150 °C/s at a quarter thickness of the slab, using a twin-belt casting method, and after winding into a coil, it is subjected to a homogenization treatment and cooled to 250 °C or less at a cooling rate of at least 500 °C/s, then cold rolled, and subsequently subjected to a solution treatment.

The twin-belt casting method is a method of casting thin slabs by pouring a melt between water-cooled rotating belts that oppose each other from above and below, so as to harden the melt by cooling through the belt surfaces. In the present invention, slabs that are 5-15 mm thick are cast by the twin-belt casting method. If the slab thickness exceeds 15 mm, it becomes difficult to wind the thin slabs into coils, and if the slab thickness is less than 5 mm, there is a loss in productivity and it becomes difficult to cast the thin slabs.

By casting a slab 5-15 mm thick using the twin-belt casting method, it is possible to make the cooling rate 40-150 °C/s at a quarter thickness of the slab. The cooling rate is computed by measuring the DAS (Dendrite Arm Spacing) by a line intersection method from observations of the microstructure in the slab at quarter thickness. When the cooling rate is less than 40 °C/s, the cast structure formed in the central portion of the slab during hardening becomes coarse, thus reducing the hemmability, while if the cooling rate exceeds 150 °C/s, Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals become 1 μm or less and the size of recrystallized grains becomes coarse at 30 μm or more.

After winding a thin slab, this coil is subjected to a homogenization treatment under appropriate conditions to fragment the Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals that have an adverse effect on hemmability, thus improving the hemmability. Furthermore, it is possible to obtain thin slabs in a state where relatively small Mg_2Si crystals that reside in the cast structure are completely dissolved into the matrix, thus raising the effectiveness of the solid solution treatment after the cold rolling process.

The reason that the cooling after the homogenization treatment is performed at a rate of at least 500 °C/s and to 250 °C or less is in order to suppress the deposition of

relatively coarse Mg_2Si as much as possible, and to dissolve the Mg and Si into the matrix in an oversaturated state.

After winding the thin slab, the coil is inserted into a batch furnace, and heated at a rate of at least 30 °C/h to 520-580 °C, at which temperature it is held for 2-24 hours to perform a homogenization treatment, after which the coil may be extracted from the batch furnace and forcibly air-cooled to room temperature at a cooling rate of at least 500 °C/h. This cooling can be performed, for example, by a fan while unwinding the coil.

The reason the heating rate to the homogenization temperature is limited to at least 30 °C/h for the homogenization treatment following winding of the thin slab is that if the heating rate is less than 30 °C/h, at least 16 hours will be required to reach the predetermined homogenization temperature, thus raising costs.

The reason the homogenization temperature is within the range of 520-580 °C is that if the temperature is less than 520 °C, the fragmentation of Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals is inadequate, and not enough to dissolve the Mg_2Si that crystallized during casting into the matrix, and if the temperature exceeds 580 °C, the metals with low melting points will melt and cause burning.

Additionally, the reason that the homogenization treatment time is set to within the range of 2-24 hours is because if the treatment time is less than 2 hours, the fragmentation of Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals is inadequate, and not enough to dissolve the Mg_2Si that crystallized during casting into the matrix, and if the treatment time exceeds 24 hours, the Mg_2Si that crystallized during casting is well-dissolved into the matrix, and the Mg and Si become saturated, resulting in cost increases.

The invention is characterized by further cold rolling this coil and performing a solution treatment. This solution treatment is preferably performed in a normal continuous annealing line (CAL).

A continuous annealing line (CAL) is an installation for performing continuous solution treatments and the like of coils, characterized by comprising inductive heating devices for performing heat treatments, water tanks for water-cooling, air nozzles for

air-cooling, and the like.

As for the solution treatment, it should preferably be performed by heating at a rate of at least 10 °C/s to 530-560 °C by means of a continuous annealing line, and holding for 30 seconds or less.

The reason the heating rate to the solution treatment temperature is limited to at least 10 °C/s in the solution treatment is that if the heating rate is less than 10 °C/s, the coil advancing speed becomes too slow, as a result of which the processing time becomes long and the cost mounts.

The reason the solution treatment temperature is set to be within the range of 530-560 °C is that if the temperature is less than 530 °C, it is not sufficient to cause Mg_2Si that crystallized while casting or precipitated while being cooled after homogenization to be dissolved into the matrix, and if the temperature exceeds 560 °C, the metals with low melting points will melt and cause burning.

Additionally, the reason the solution treatment time is restricted to be within 30 seconds is that in the case of treatment times exceeding 30 seconds, Mg_2Si that crystallized while casting or precipitated while being cooled after homogenization is well-dissolved into the matrix, and the Mg and Si become saturated, thereby slowing the coil advancement speed, as a result of which the processing time is increased and the costs mount.

The invention is characterized by cooling to room temperature at a rate of at least 10 °C/s after the solution treatment. The reason the cooling rate after the solution treatment is at least 10 °C/s is that if the cooling rate is less than 10 °C/s, Si is deposited in the crystal grain boundary during the cooling step, thus reducing the hemmability.

After performing the aforementioned homogenization treatment on the thin slab, it is further cold rolled, subjected to a solution treatment and cooled to room temperature at a rate of at least 10 °C/s, and after the coil is left at room temperature, it may be held for 30 seconds or less at 260-300 °C in a continuous annealing line, then cooled to room temperature at 10 °C/s.

This solution treatment and restoration treatment are preferably performed in a

normal continuous annealing line. A continuous annealing line (CAL) is an installation for performing continuous solution treatments and the like of coils, characterized by comprising inductive heating devices for performing heat treatments, water tanks for water-cooling, air nozzles for air-cooling, and the like. Due to the restoration treatment, it is possible to re-dissolve GP zones that appear due to natural ageing when left at room temperature after a solution treatment, thus enabling adequate strength to be obtained after heating for coating and baking.

Additionally, in order to obtain adequate strength after heating for coating and baking, it is left at room temperature after the solution treatment and subjected to a restoration treatment at 260-300 °C. If the restoration treatment temperature is less than 260 °C, adequate bake-hardenability cannot be obtained, and if it exceeds 300 °C, the hemmability is reduced.

The reason the time over which the restoration treatment temperature is held is restricted to within 30 seconds is that if the treatment time exceeds 30 seconds, it is not possible to adequately re-dissolve the GP zones that appear due to natural ageing when left at room temperature after the solution treatment, in addition to which the coil advancement speed is too slow, as a result of which the treatment time is long and the costs mount.

After performing the aforementioned homogenization treatment on the thin slab, it can be further cold rolled, subjected to a heat solution treatment in a continuous annealing line, water-cooled to 250 °C or less at a cooling rate (first cooling rate) of at least 10 °C/s, then air-cooled to 60-100 °C at a cooling rate (second cooling rate) of 1-20 °C/s, coiled up and cooled to room temperature.

This heat solution treatment and subsequent cooling are preferably performed in a normal continuous annealing line (CAL). During this heat solution treatment and subsequent cooling, a heat treatment (preliminary ageing) can be performed to evenly generate nuclei for β" deposition in the matrix, to obtain adequate strength after heating for coating and baking.

After subjecting the thin slab to a homogenization treatment and further cold rolling,

it may be subjected to a solution treatment by heating to 530-560 °C at a rate of at least 10 °C/s, then holding for 30 seconds or less, then cooled to room temperature at a rate of at least 10 °C/s, thereafter subjected to a restoration treatment by holding within a range of 260-300 °C for 30 seconds, then cooled to 60-100 °C at a cooling rate of at least 1 °C/s, coiled up and subjected to a preliminary ageing treatment by cooling to room temperature.

This solution treatment and subsequent cooling, and restoration treatment and subsequent cooling are preferably performed in a normal continuous annealing line (CAL). With this production method, not only is it possible to re-dissolve GP zones that appear due to natural ageing when left at room temperature after the solution treatment, but it is also possible to perform a heat treatment (preliminary ageing) to generate nuclei for β" deposition, thus further improving the resistance after coating and baking.

Next, the significance of the alloy ingredients of the present invention and the reasons for their limitations shall be explained. The essential element Mg is dissolved in the matrix after the heat solution treatment, and is deposited as a reinforcing phase together with Si upon heating for coating and baking, thereby improving the strength. The reason the Mg content is limited to 0.30-1.00 wt% is that the effect is small if less than 0.30 wt%, and if more than 1.00 wt%, the hemmability after the solution treatment is reduced. A more preferable range for the Mg content is 0.30-0.70 wt%.

The essential element Si is deposited together with Mg as an intermediary phase of Mg_2Si known as β" or an analogous reinforcing phase upon being heated for coating and baking, thereby increasing the strength. The reason the Si content is limited to 0.30-1.20 wt% is that if less than 0.30 wt%, its effects are minimal, and if more than 1.20 wt%, the hemmability is reduced after the heat solution treatment. A more preferable range of Si content is 0.60-1.20 wt%.

The essential element Fe, when coexisting with Si and Mn, generates many Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals of a size of 5 μm or less upon casting, so that re-crystallized nuclei are increased, as a result of which the recrystallized grains are refined and sheets of exceptional formability are obtained. If the Fe content is less than 0.05 wt%,

the effects are not very remarkable. If it exceeds 0.50 wt%, coarse Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals are formed upon casting, thus not only reducing the hemmability but also reducing the amount of Si dissolved in the thin slabs, as a result of which the bake-hardenability of the final sheets is reduced. Therefore, the preferable range of Fe content is 0.05-0.50 wt%. A more preferable range of Fe content is 0.05-0.30 wt%.

The essential element Mn is added as an element to refine the re-crystallized grains. By keeping the size of the re-crystallized grains relatively small at 10-25 μm, it is possible to form sheets with exceptional formability. If the Mn content is less than 0.05 wt%, the effect is not adequate, and if it exceeds 0.50 wt%, coarse Al-Fe-Si crystals and Al-(Fe·Mn)-Si crystals are formed upon casting, thus not only reducing the hemmability but also reducing the amount of Si dissolved in the thin slabs, as a result of which the bake-hardenability of the final sheets is reduced. Therefore, the preferable range of Mn content is 0.05-0.50 wt%. A more preferable range of Mn content is 0.05-0.30 wt%.

The essential element Ti will not inhibit the effects of the present invention if it is contained at 0.10 wt% or less, and it can function as a crystal grain refiner for the thin slabs, so as to reliably prevent casting defects of the slabs such as cracks or the like. If the Ti content is less than 0.005 wt%, the effects are not adequate, and if the Ti content exceeds 0.10 wt%, coarse intermetallic compounds such as $TiAl_3$ and the like are formed during casting, thus greatly reducing the hemmability. Therefore, the preferable range of Ti content is 0.005-0.10 wt%. A more preferable range for the Ti content is 0.005-0.05 wt%.

The optional element Cu is an element that promotes age-hardening and raises the bake-hardenability. If the Cu content is less than 0.05 wt%, the effect is small, and if it exceeds 0.70 wt%, the yield strength of the sheets becomes high after a preliminary ageing treatment, and not only does the hemmability decrease, but the reduction in corrosion resistance is also marked. Therefore, the Cu content is preferably within a range of 0.05-0.70 wt%. The Cu content is more preferably 0.10-0.60 wt%.

The optional element Zr is added as an element for refining the re-crystallized grains. If the Zr content is less than 0.05 wt%, the effect is not adequate, and if it exceeds 0.40 wt%, coarse Al-Zr crystals are created during slab casting, thus reducing the

hemmability. Therefore, the Zr content is preferably within a range of 0.05-0.40 wt%. The Zr content is more preferably within a range of 0.05-0.30 wt%.

As explained above, the present invention allows an Al-Mg-Si alloy sheet for use in automotive body sheets having exceptional bake-hardenablitiy and hemmability after a final anneal to be produced at low cost. While a restoration treatment or high-temperature winding is required to suppress natural ageing as with conventional methods, the steps such as facing, hot rolling and the like that precede these steps can be largely simplified, thus greatly reducing the total production cost.

Herebelow, the best modes of the present invention shall be described using examples.

Example 1

In the below-given examples, the samples after cold rolling are not coils but all cut sheets. Therefore, in order to simulate the step of continuous annealing of a coil in a continuous annealing line (CAL), a solution treatment of the samples in a salt bath and a cold water quench or 85 °C water quench were employed.

After degassing melts having the compositions shown in Table 1, they were cast into slabs 7 mm thick by means of a twin-belt casting method. The DAS (Dendrite Arm Spacing) was measured by an intersection method from observation of the microstructures at a quarter-thickness of the slab, and the cooling rate 75 °C/s was computed. A predetermined homogenization treatment was performed on the slabs which were then cooled to room temperature at a predetermined cooling rate, and cold rolled to form sheets of 1 mm thickness. Next, solution treatments were performed on these cold rolled sheets in a salt bath, and they were either 1) quenched in 85 °C water and immediately inserted into an annealer with a predetermined atmospheric temperature to perform a heat treatment under predetermined conditions, or 2) quenched in cold water, left at room temperature for 24 hours, then subjected to a heat treatment under predetermined conditions. Furthermore, in order to simulate automobile coating steps, they were held for one week at room temperature after the heat treatment, and measured for 0.2% yield strength, further baked at 180 °C for 30 minutes, and again measured for 0.2% yield strength.

The difference in yield strength before and after the baking treatment was taken as the bake-hardenability, and those exceeding 80 MPa were judged to have excellent bake-hardenability. In order to simulate hemmability, the sheets prior to baking were preliminarily warped by 5%, then bent into a U shape using a jig having a radius r = 0.5 mm, then 1 mm thick spacers were inserted and they were bent 180°. Those which did not crack were ranked O and those which cracked were ranked X. The detailed sheet production steps and evaluation results are shown in Table 2-6.

[Table 1]

TABLE 1 Alloy Composition

(wt%)

Alloy No.	Mg	Si	Fe	Mn	Cu	Ar	Ti
A	0.5	0.7	0.2	0.2	-	-	0.02
B	0.5	0.8	0.2	0.2	-	-	0.02
C	0.6	0.8	0.2	0.2	-	-	0.02
D	0.5	1	0.2	0.2	0.5	-	0.02
E	0.5	0.8	0.2	0.2	-	0.15	0.02
F	0.4	1.2	0.2	0.2	0.1	-	0.02

Table 2 shows the results for cases in which the homogenization conditions and cooling rate after the homogenization treatment were changed. After the homogenization treatment, the slabs were cold rolled to a thickness of 1 mm, these cold rolled sheets were subjected to a solution treatment by holding for 15 seconds at a predetermined temperature by means of a salt bath, then quenched with 85 °C water, and immediately inserted into an annealer with an atmospheric temperature of 85 °C to perform a preliminary ageing of 8 hours. Those falling within the scope of conditions of the present invention (1-7) had exceptional bake-hardenability and hemmability. Those that did not undergo a homogenization treatment (8, 10) had poor bake-hardenability and hemmability. Additionally, those which had a slow cooling rate after the homogenization treatment had poor bake-hardenability (9).

[Table 2]

TABLE 2 Cooling Rate after Homogenization and Bake-Hardenability/Hemmability

	ID	Alloy No.	Cast Type/ Slab Thick. (mm)	Homogenization Treatment			
				Heating Rate (°C/h)	Holding Temp (°C)	Holding Time (h)	Cooling Rate (°C/h)
Present Invention	1	A	twin-belt / 7	30	560	5	1500
	2	B	twin-belt / 7	50	560	6	1700
	3	B	twin-belt / 7	50	550	5	500
	4	C	twin-belt / 7	30	530	10	1000
	5	D	twin-belt / 7	40	530	10	1000
	6	E	twin-belt / 7	40	530	10	1000
	7	F	twin-belt / 7	50	550	6	1000
Comp. Example	8	A	twin-belt / 7	None			
	9	B	twin-belt / 7	50	560	6	250
	10	B	twin-belt / 7	None			

	ID	Cold Roll Sheet Thick.	Sol. Treat. Temp.	Prelim. Ageing	Yield Str. before/after Baking (Mpa)	Bake-Hard. (MPa)	Hem.
Present Invention	1	1 mm	550 °C	85 °C × 8 h	100/192	92	O
	2	1 mm	550 °C	85 °C × 8 h	110/210	100	O
	3	1 mm	530 °C	85 °C × 8 h	95/175	80	O
	4	1 mm	540 °C	85 °C × 8 h	107/209	102	O
	5	1 mm	550 °C	85 °C × 8 h	122/221	99	O
	6	1 mm	550 °C	85 °C × 8 h	115/213	98	O
	7	1 mm	550 °C	85 °C × 8 h	117/208	91	O
Comp. Example	8	1 mm	550 °C	85 °C × 8 h	110/158	48	X
	9	1 mm	550 °C	85 °C × 8 h	90/145	55	O
	10	1 mm	550 °C	85 °C × 8 h	92/160	68	X

Table 3 shows the results when the temperatures/times of the homogenization treatment are changed. After the homogenization treatment, the slabs were cold rolled to a thickness of 1 mm, these cold rolled sheets were subjected to a solution treatment by holding for 15 seconds at a predetermined temperature by means of a salt bath, then quenched in 85 °C water and immediately entered into an annealer with an atmospheric temperature of 85 °C to perform a preliminary ageing of 8 hours. Those falling within the scope of conditions of the present invention (11-14) had exceptional bake-hardenability and hemmability. Those that had a low homogenization temperature (15) or had a short holding time (16) had poor bake-hardenability and hemmability.

[Table 3]

TABLE 3 Homogenization Temperature/Time and Bake-Hardenabilit/Hemmability

	ID	Alloy No.	Cast Type/ Slab Thick. (mm)	Homogenization Treatment			
				Heating Rate	Holding Temp	Holding Time	Cooling Rate
				(°C/h)	(°C)	(h)	(°C/h)
Present Invention	11	B	twin-belt / 7	30	560	5	1500
	12	B	twin-belt / 7	50	560	6	1500
	13	C	twin-belt / 7	50	550	5	1500
	14	C	twin-belt / 7	30	530	10	1500
Comp. Example	15	B	twin-belt / 7	50	500	6	1500
	16	B	twin-belt / 7	50	560	1	1500

	ID	Cold Roll Sheet Thick.	Sol. Treat. Temp.	Prelim. Ageing	Yield Str. before/after Baking (Mpa)	Bake-Hard. (MPa)	Hem.
Present Invention	11	1 mm	550 °C	85 °C × 8 h	110/210	100	O
	12	1 mm	550 °C	85 °C × 8 h	111/213	103	O
	13	1 mm	530 °C	85 °C × 8 h	107/209	102	O
	14	1 mm	540 °C	85 °C × 8 h	112/215	103	O
Comp. Example	15	1 mm	550 °C	85 °C × 8 h	95/165	70	X
	16	1 mm	550 °C	85 °C × 8 h	100/175	75	X

Table 4 shows the results when the homogenization conditions and restoration conditions were changed. After the homogenization treatment, the slabs were cold rolled to a thickness of 1 mm, these cold rolled sheets are subjected to a solution treatment by holding for 15 seconds at a predetermined temperature by means of a salt bath, then quenched in cold water, and after leaving at room temperature for 24 hours, subjected to a restoration treatment by holding for 15 seconds at a predetermined temperature. Those falling within the scope of conditions of the present invention (17-20) had exceptional bake-hardenability and hemmability. Those that had a low restoration temperature (reheating temperature) (21) had poor bake-hardenability. Those whose restoration temperature (reheating temperature) was too high (22) had poor hemmability. Furthermore, even when the restoration conditions were within the scope of the present invention, those in which the homogenization temperature was low (23) or the holding time was short (24) had poor hemmability. Those in which the cooling rate after the homogenization treatment was slow (25) had poor bake-hardenability.

[Table 4]

TABLE 4 Homogenization Method/Reheat Temperature and Bake-Hardenability/Hemmability

	ID	Alloy No.	Cast Type/ Slab Thick. (mm)	Homogenization Treatment			
				Heating Rate	Holding Temp	Holding Time	Cooling Rate
				(°C/h)	(°C)	(h)	(°C/h)
Present Invention	17	B	twin-belt / 7	30	560	5	1500
	18	B	twin-belt / 7	50	560	6	2000
	19	C	twin-belt / 7	50	550	5	1000
	20	C	twin-belt / 7	30	530	10	2500
Comp. Example	21	B	twin-belt / 7	50	560	6	1500
	22	B	twin-belt / 7	50	560	6	1500
	23	B	twin-belt / 7	50	500	6	500
	24	B	twin-belt / 7	50	560	1	1000
	25	B	twin-belt / 7	50	560	6	200

	ID	Cold Roll Sheet Thick.	Sol. Treat. Temp.	Prelim. Ageing	Yield Str. before/after Baking (Mpa)	Bake-Hard. (MPa)	Hem.
Present Invention	17	1 mm	550 °C	270	110/210	100	O
	18	1 mm	550 °C	270	111/213	103	O
	19	1 mm	530 °C	290	107/209	102	O
	20	1 mm	540 °C	290	112/215	103	O
Comp. Example	21	1 mm	550 °C	240	95/170	75	O
	22	1 mm	550 °C	310	127/229	102	X
	23	1 mm	550 °C	290	97/197	100	X
	24	1 mm	550 °C	280	90/160	70	X
	25	1 mm	550 °C	290	95/145	50	O

Table 5 shows the results when the homogenization conditions and cooling pattern after the solution treatment were changed. The cooling rate after the solution treatment was divided into two stages, with the cooling rate from the solution temperature to an intermediate temperature being defined as the first cooling rate and the cooling rate from the intermediate temperature to the coil-up temperature being defined as the second cooling rate. After the homogenization treatment, the slabs were cold rolled to a thickness of 1 mm, and these cold rolled sheets were subjected to a solution treatment by holding for 15 seconds at a predetermined temperature by means of a salt bath, after which they were cooled to the intermediate temperature at the first cooling rate, then cooled to the coil-up temperature at the second cooling rate, and thereafter cooled to room temperature at 5 °C/h.

Those falling within the scope of the present invention (26-28) had exceptional bake-hardenability and hemmability. Those in which the first cooling rate after the solution

treatment was slow (29), those in which the second cooling rate was slow (31) or those in which the intermediate temperature was too high (30) had poor hemmability. Those in which the coil-up temperature was too low (32) had poor bake-hardenability. Conversely, those in which the coil-up temperature was too high (33) had poor hemmability. Furthermore, those in which the homogenization treatment temperature was too low (34) or the holding time was too short (35) had poor hemmability. Those in which the cooling rate after the homogenization treatment was too slow (36) had poor bake-hardenability.

[Table 5]

TABLE 5 Homogenization Method/Coil-up Temperature and Bake-Hardenability/Hemmability

	ID	Alloy No.	Cast Type/ Slab Thick. (mm)	Homogenization Treatment			
				Heating Rate (°C/h)	Holding Temp (°C)	Holding Time (h)	Cooling Rate (°C/h)
Present Invention	26	B	twin-belt / 7	30	560	5	1500
	27	B	twin-belt / 7	50	560	6	2000
	28	B	twin-belt / 7	50	550	5	1000
Comp. Example	29	B	twin-belt / 7	50	560	6	1500
	30	B	twin-belt / 7	50	560	6	1500
	31	B	twin-belt / 7	50	560	6	1500
	32	B	twin-belt / 7	50	560	6	1500
	33	B	twin-belt / 7	50	560	6	2000
	34	B	twin-belt / 7	50	500	6	1000
	35	B	twin-belt / 7	50	560	1	1000
	36	B	twin-belt / 7	50	560	6	200

	ID	Cold Roll Sheet Thick.	Sol. Treat. Tem. (°C)	First Cool Temp (°C)	Int. Temp (°C)	Sec. Cool Temp (°C)	Coil Up Temp (°C)	YS b/a Bak. (Mpa)	Bake-Hard. (MPa)	Hem
Present Invention	26	1 mm	550	100	200	20	85	110/210	101	O
	27	1 mm	550	100	200	20	70	105/207	102	O
	28	1 mm	530	100	200	20	90	101/211	100	O
Comp. Example	29	1 mm	550	5	200	20	80	106/201	95	X
	30	1 mm	550	100	300	20	80	101/197	96	X
	31	1 mm	550	100	250	1	80	102/198	96	X
	32	1 mm	550	100	200	20	50	112/165	53	O
	33	1 mm	550	100	200	15	110	130/240	110	X
	34	1 mm	550	100	200	20	85	97/197	100	X
	35	1 mm	550	100	200	20	85	104/194	90	X
	36	1 mm	550	100	200	20	80	89/134	45	O

Table 6 shows the results when the restoration treatment temperature (reheating temperature) after the solution treatment and coil-up temperature were changed. After the homogenization treatment, the slabs were cold rolled to a thickness of 1 mm, these cold

rolled sheets are subjected to a solution treatment by holding for 15 seconds at a predetermined temperature by means of a salt bath, then quenched in cold water, and after leaving at room temperature for 24 hours, held for 15 seconds at a predetermined temperature (preheating temperature) and cooled to a predetermined coil-up temperature at 10 °C/s, then further cooled to room temperature at 10 °C/h. Those falling within the scope of conditions of the present invention (37-40) had exceptional bake-hardenability and hemmability. Those in which the restoration treatment temperature (reheating temperature) was too high (41) had poor hemmability. Those in which the restoration treatment temperature (reheating temperature) was too low (42) had reduced bake-hardenability. Those in which the coil-up temperature was too low (43) had poor bake-hardenability. Those in which the coil-up temperature was too high (44) had poor hemmability.

[Table 6]

TABLE 6 Reheat Temperature/Coil-up Temperature and Bake-Hardenability/Hemmability

	ID	Alloy No.	Sol. Treat. Tem. (°C)	Reheat Temp (°C)	Coil Up Temp (°C)	Yield Str. before/after Baking (Mpa)	Bake-Hard. (MPa)	Hem.
Present Invention	37	B	550	270	85	121/231	110	O
	38	B	550	270	90	125/237	114	O
	39	B	530	290	70	117/228	111	O
	40	B	540	290	80	119/231	112	O
Comp. Example	41	B	550	320	85	124/234	110	X
	42	B	550	250	80	111/198	87	O
	43	B	550	260	40	110/185	75	O
	44	B	550	290	120	131/249	118	X

Homogenization: 550 °C × 6 h Cooling Rate after Homogenization: 1000 °C/h

INDUSTRIAL APPLICABILITY

According to the present invention, rolled sheets of Al-Mg-Si alloy that are suitable for forming by bending, press forming and the like of automotive parts, household appliances and the like can be produced at a low cost relative to the conventional art.